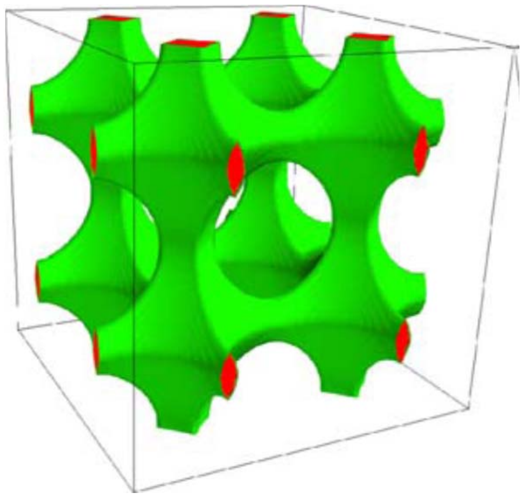
SILICON BASED SELECTIVE THERMAL EMITTERS.

R.Alcubilla
Micro and Nanotechnologies Group
UPC-Barcelona



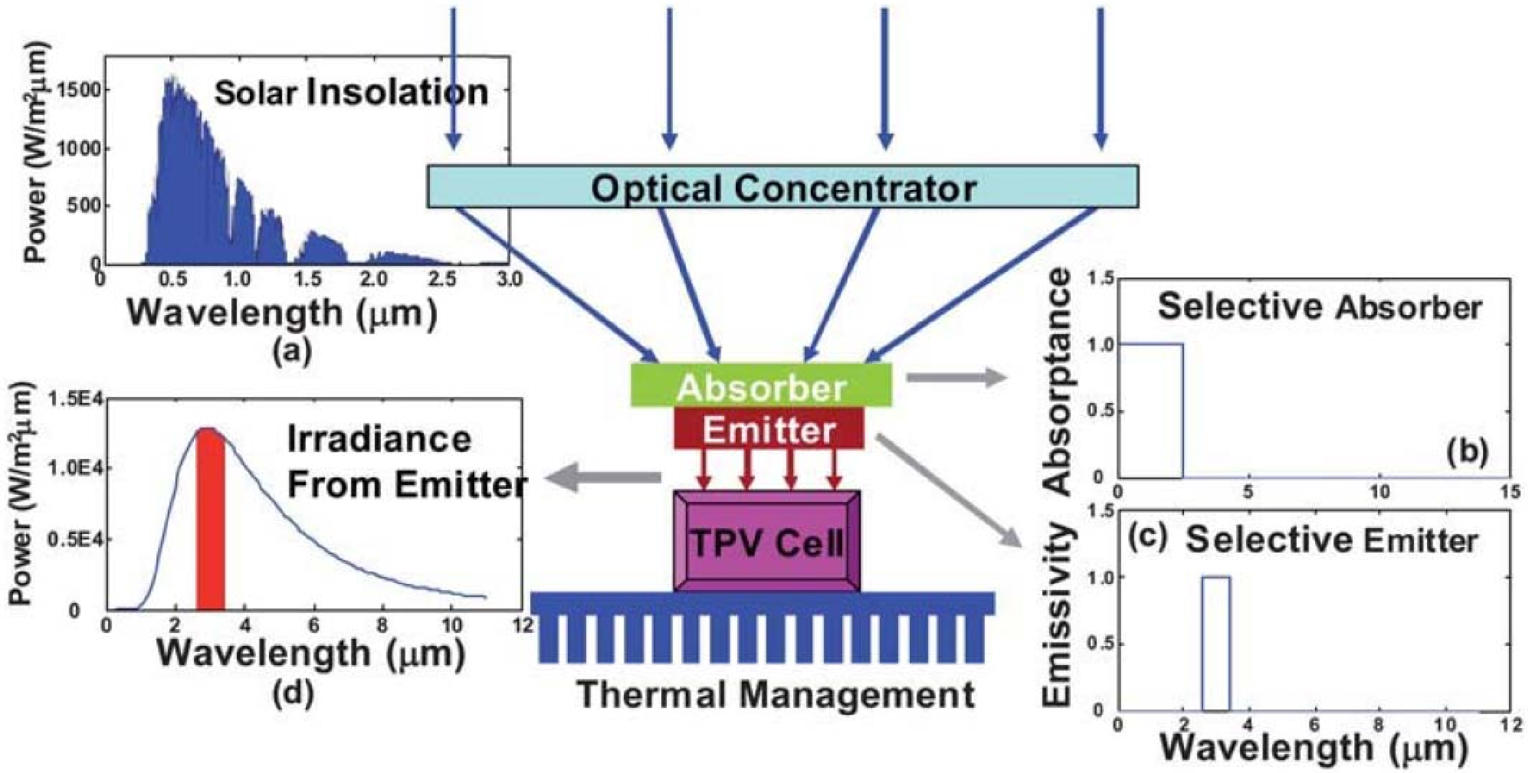
UNIVERSITAT POLITÈCNICA DE CATALUNYA

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

David Hernandez
Trifon Trifonov
Moisés Gárin
Didac Vega
Angel Rodriguez

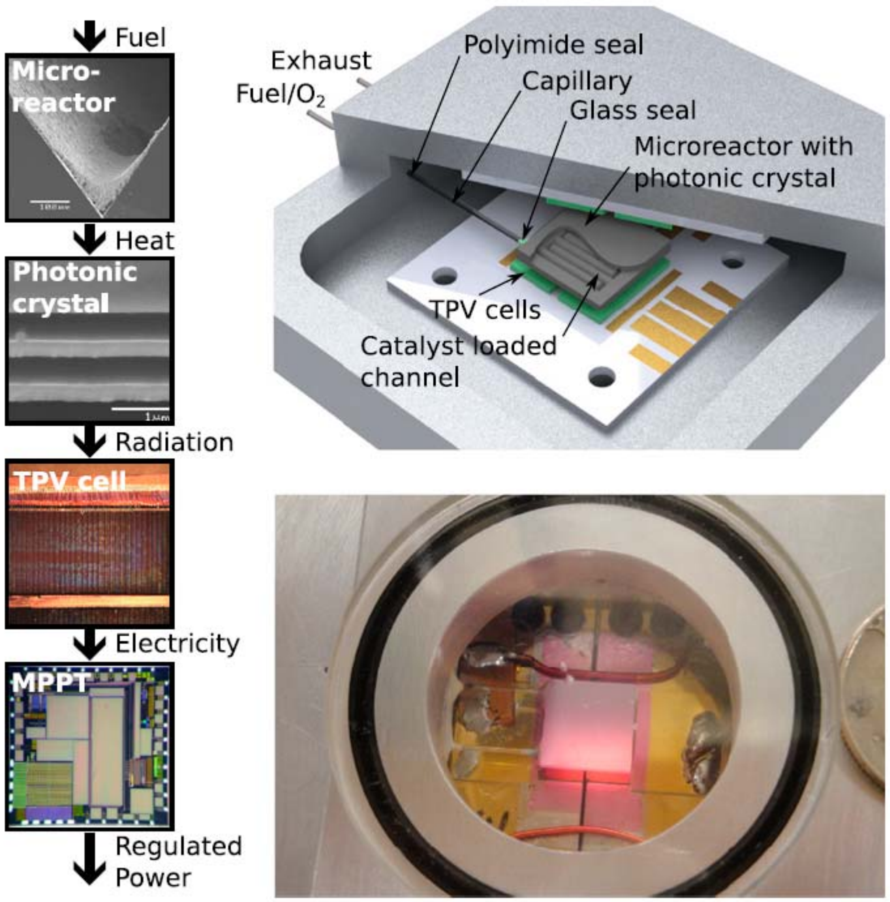
nanophotonics for energy efficiency

MOTIVATION: SELECTIVE EMITTERS FOR TPV



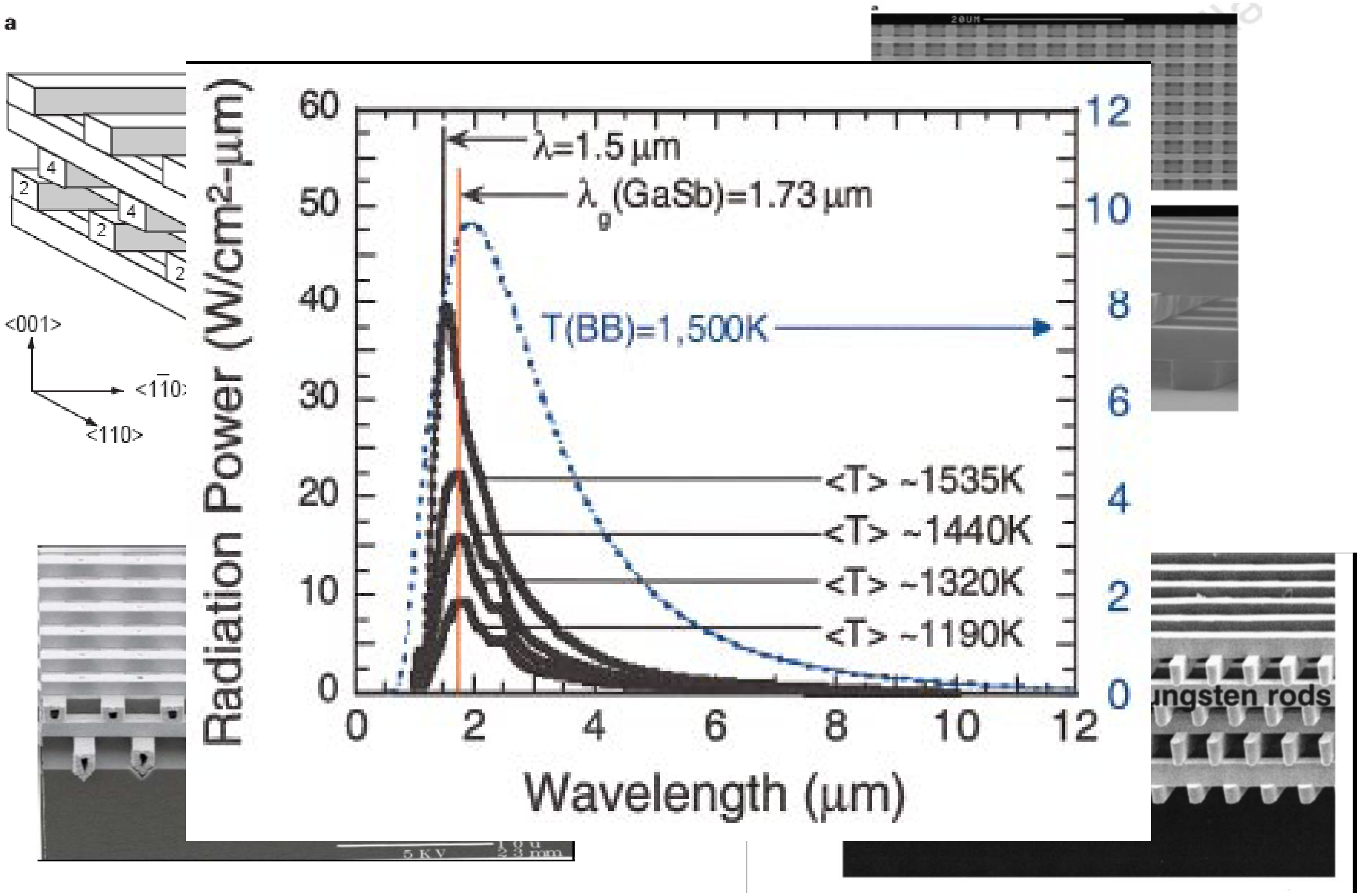
Energy Environ. Sci., 2009, 2, 559–588 | 567

Recent developments



PNAS | April 2, 2013 | vol. 110 | no. 14 | 5309–5314

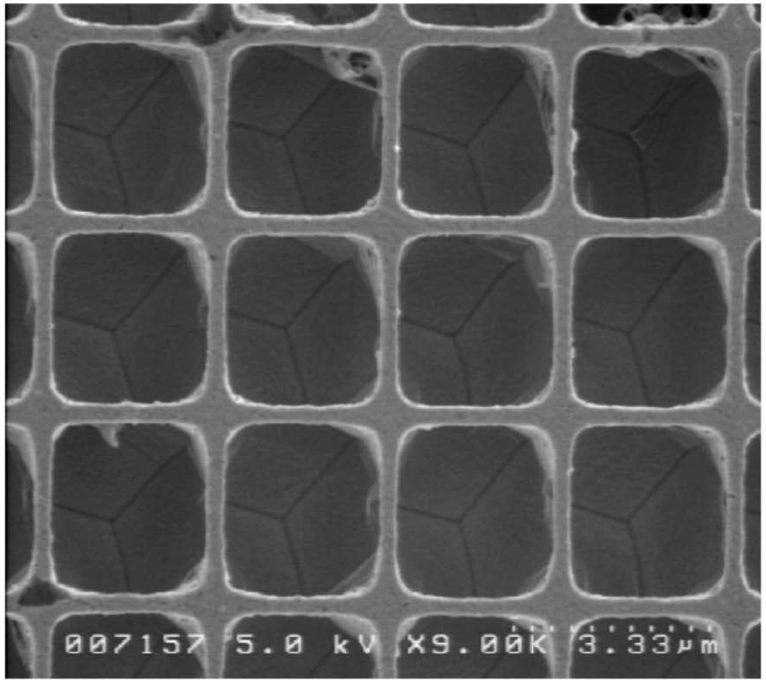
Selective thermal emitters I



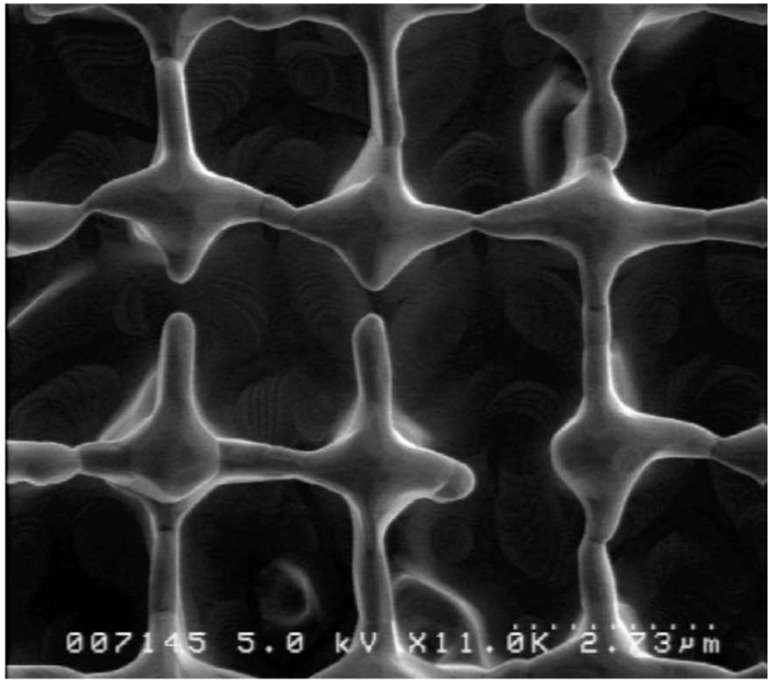
Fleming et al
Nature 417, 2002

Lin et al
APL 83, 2, 2003

Stability at high temperatures



(a)

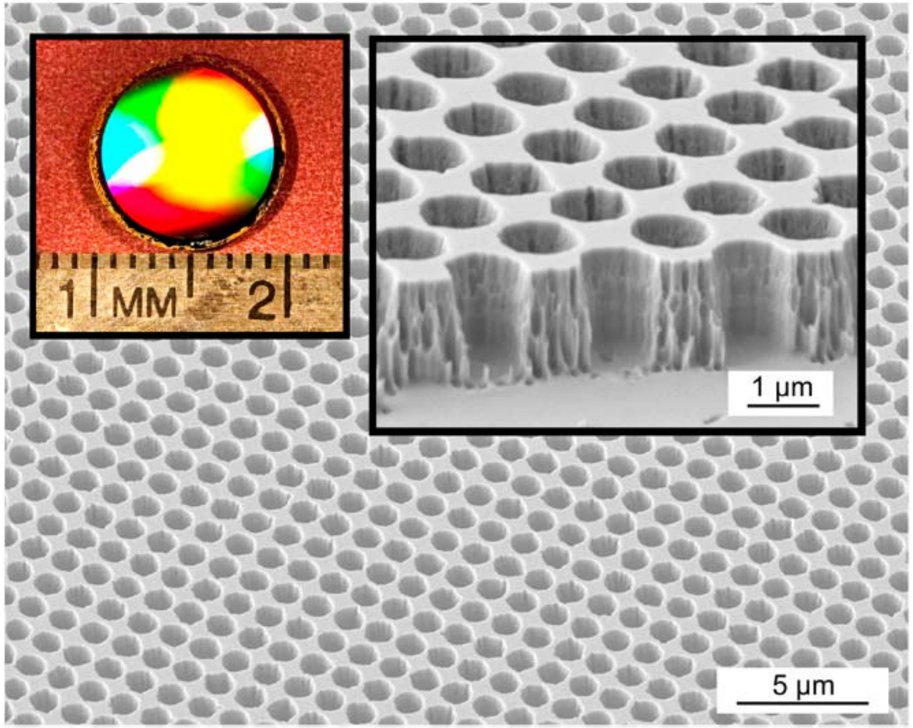


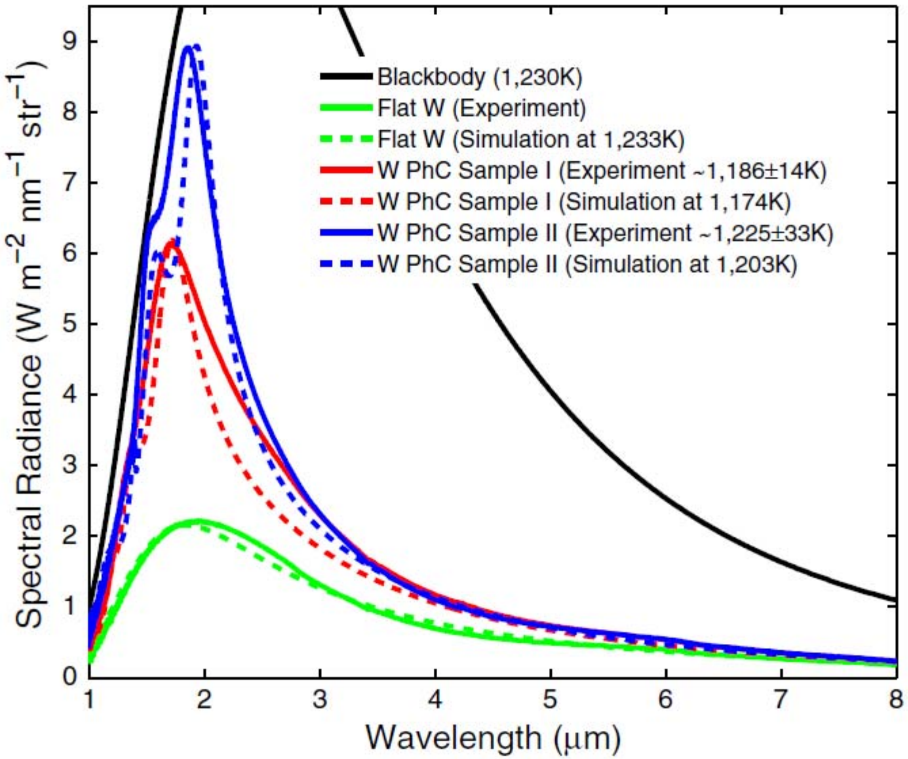
(b)

> 1000º C

Thermal Radiation at the Nanoscale (TRN 07)
Les Houches
May 21-25, 2007

Selective thermal emitters II

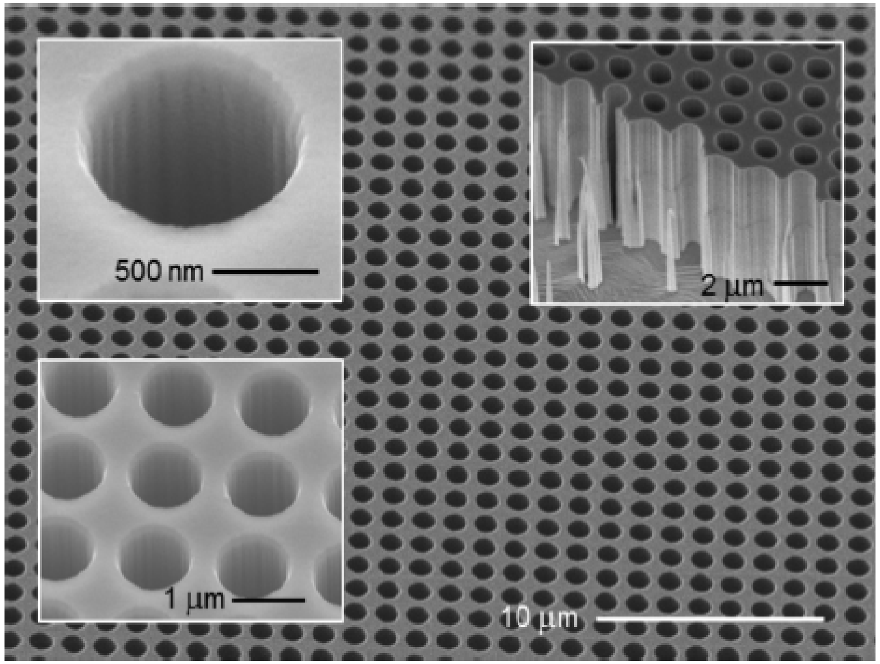


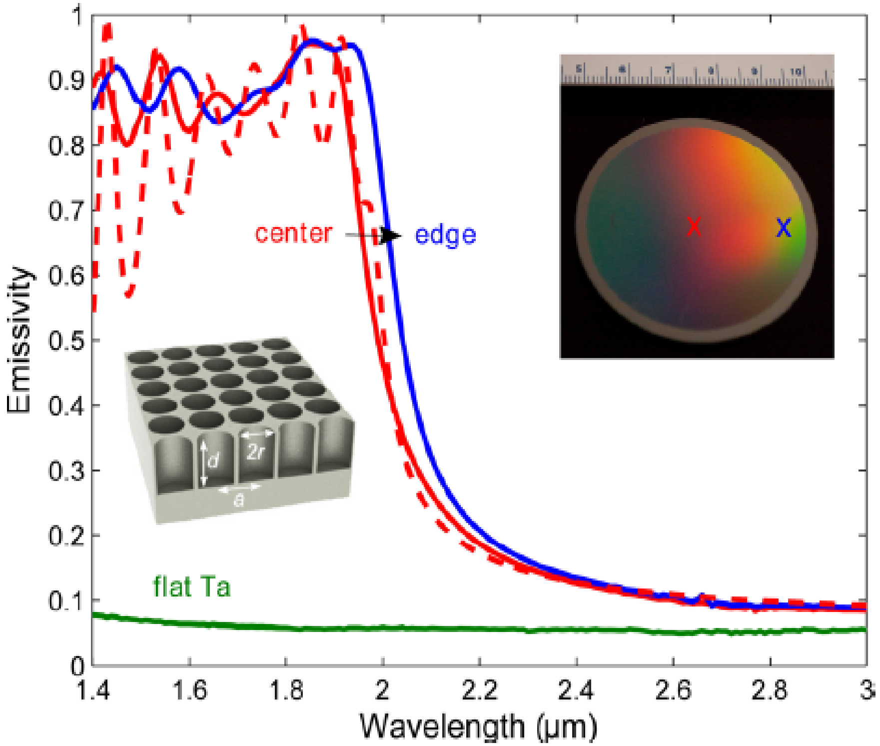


Single crystal W 99,999%
Thermal cycling 1200 K ,1hour

Yi Xiang Yeng
www.pnas.org/cgi/doi/10.1073/pnas.1120149109
December 13, 2011

Selective thermal emitters III





Polycrystalline Ta
Room T emissivity measurements
Claim 1 week at 910ºC

J. Vac. Sci. Technol. B **31**, 011802 (2013); doi: 10.1116/1.4771901

Why not 3D PC on Silicon?

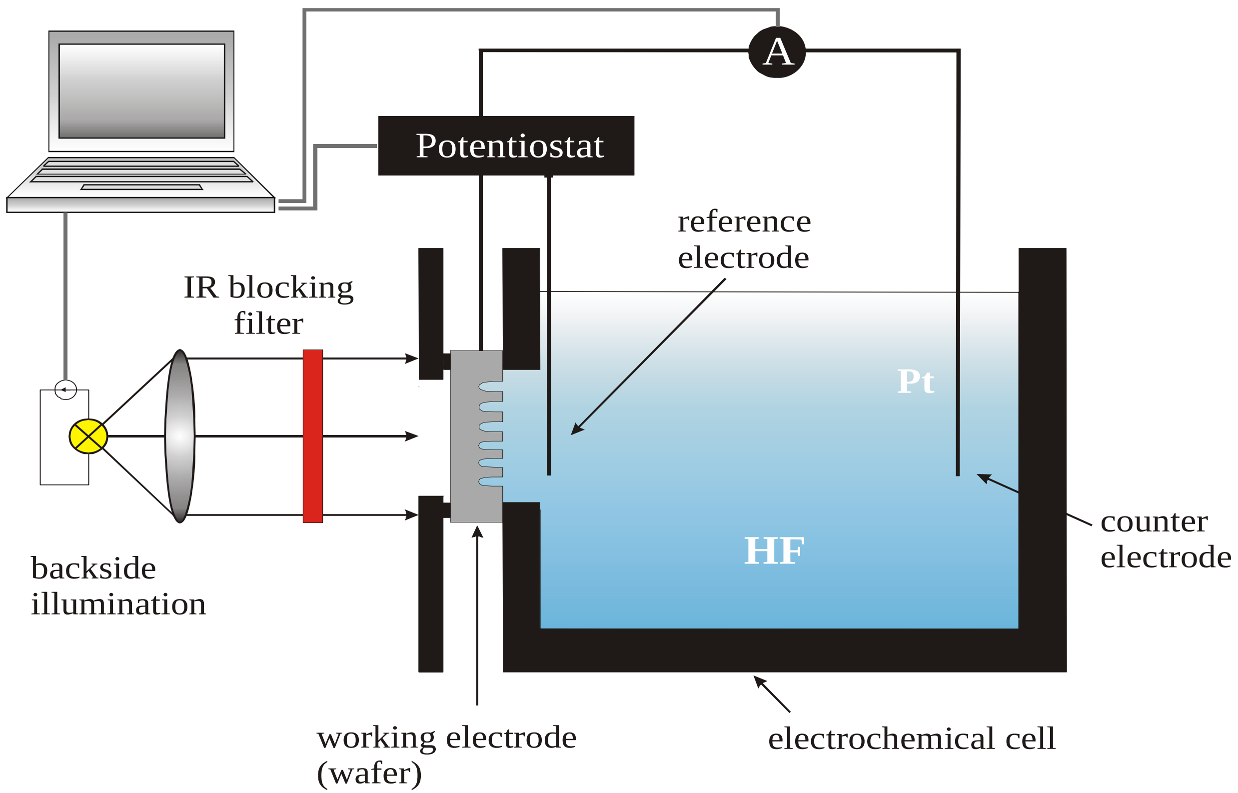
We can cover with metal later. (Silicon template)+ ALD

Conventional microelectronic oxidation 800ºC-1200ºC.

Electrochemical dissolution of Si. →Macroporous Silicon allows the fabrication of 3 D PC.

Experience in the group.

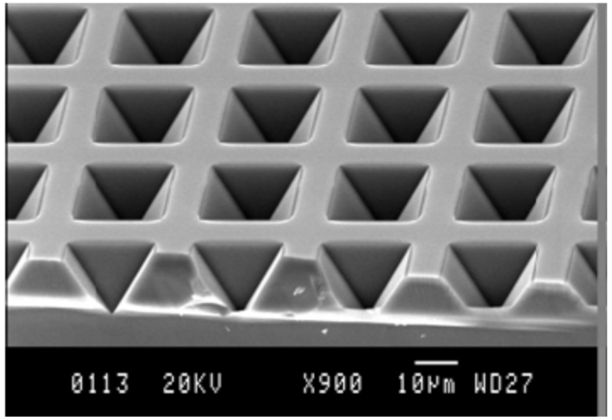
Electrochemical etching of Silicon/1



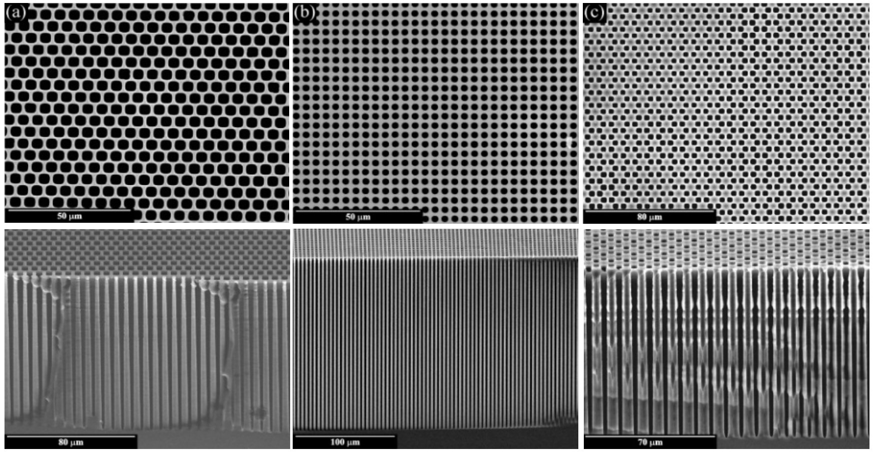
Three electrode electrochemical cell.
Potentiostat for direct control and regulation of applied voltage
Feedback controlled back-side illumination

Electrochemical etching of Silicon/1

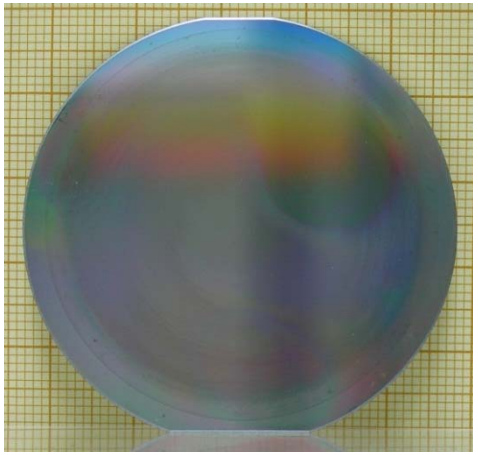
1- Lithography

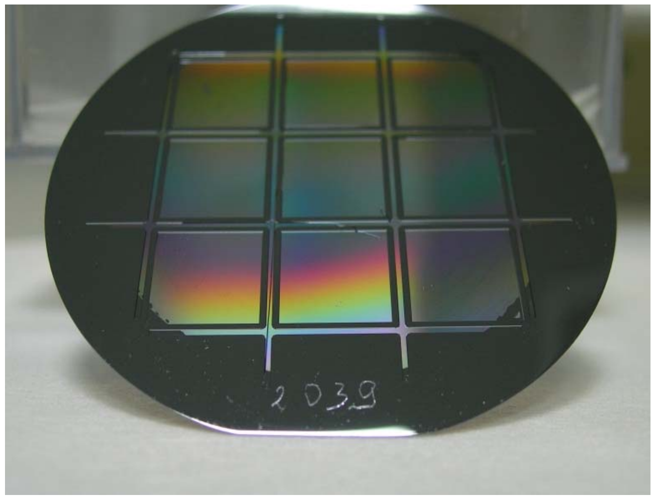


2- Electrochemical etching



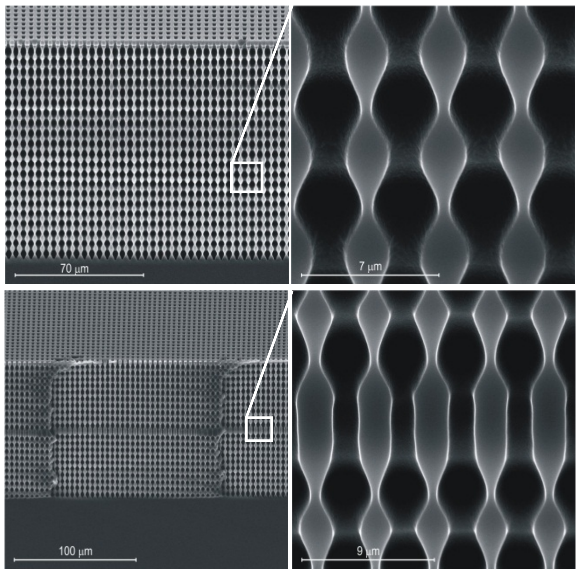
3- Control: current, voltage, light, temperature, lifetime, bubbles …

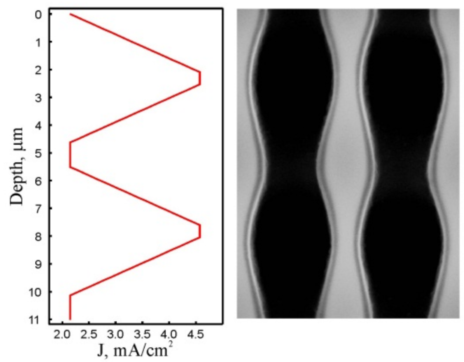


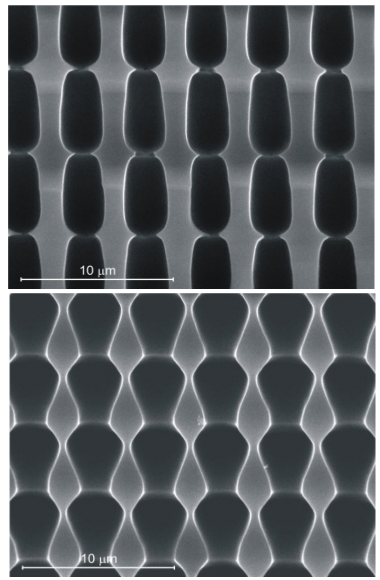


3D macroporous Silicon

In the electrochemical etching process, the pore diameter is solely determined by the applied etching current, which itself is adjusted by controlling the intensity of backside illumination. Periodic variations of pore diameter in depth can be achieved by modulating the light intensity. The etching current profiles can be properly designed to obtain structures with different shape.



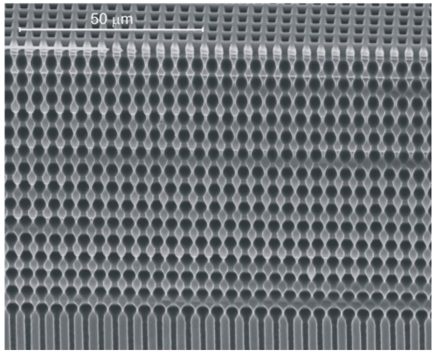


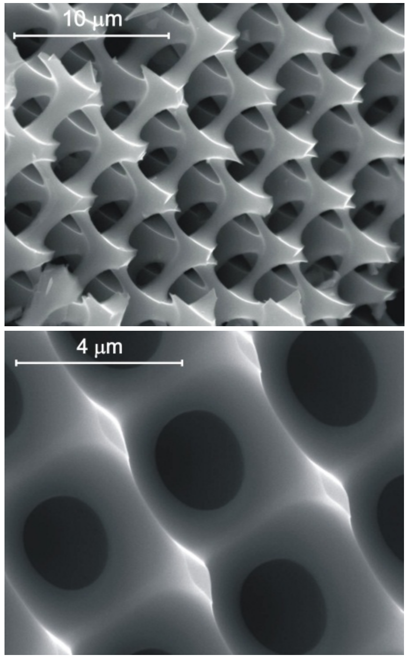


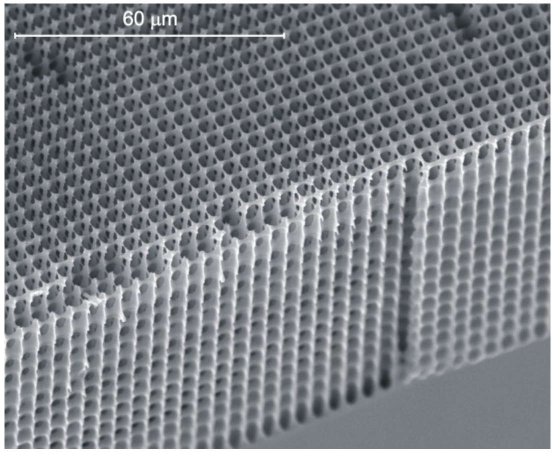
T.Trifonov et al.
Sensors and Actuators A (2008)

3D macroporous Silicon

After few multiple oxidation/oxide-stripping cycles, adjacent pores become interconnected because the pore walls erode at the positions of diameter is maximum. The opened windows between the pores have circular or oval shapes. The formed 3D structure resembles a simple cubic lattice consisting of overlapping air spheres in silicon.

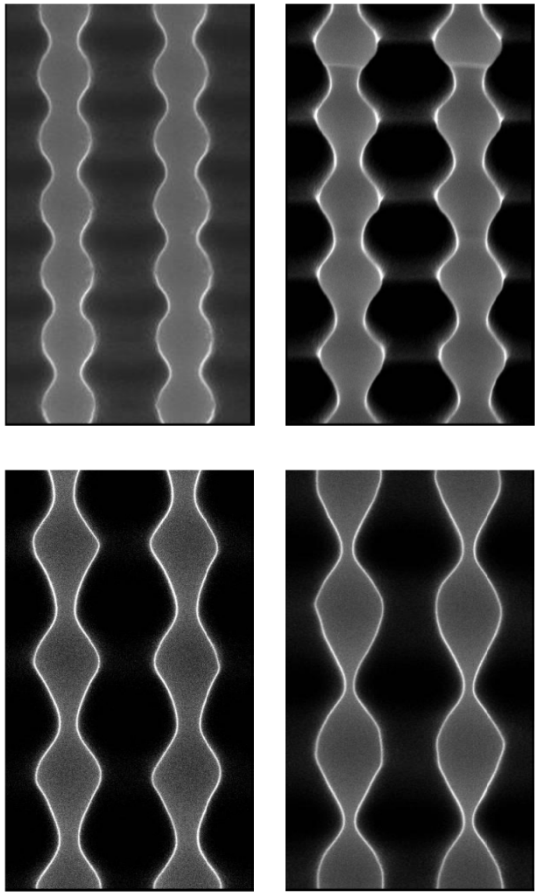






T. Trifonov et al
SPIE Conference, May, 2007, Spain

3D macroporous Silicon



M. Garin et al APL 2007

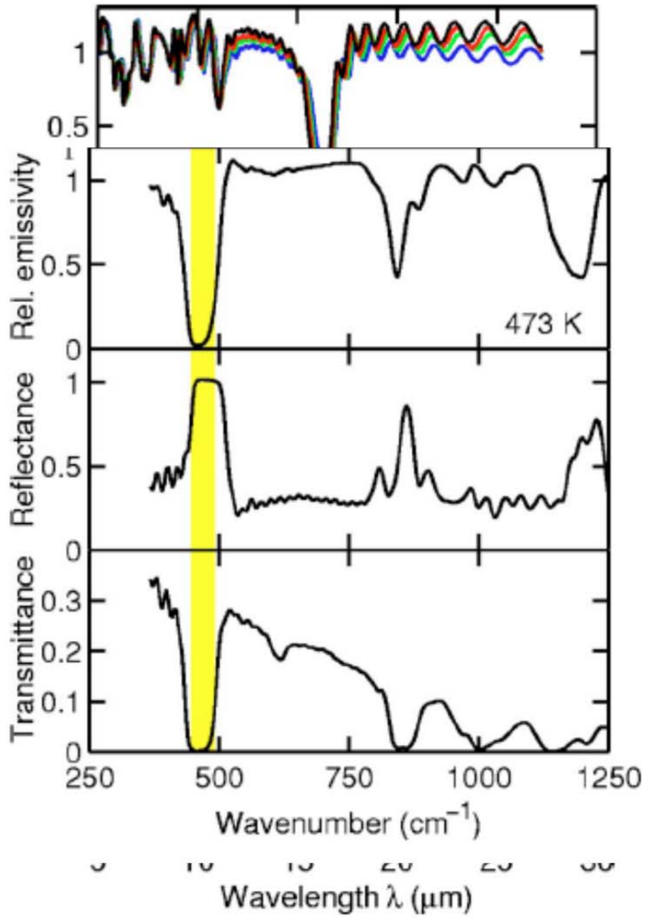


FIG. 3. (Color online) Normalized emittance spectra of 3D macroporous samples with periodicities along the pore axis of 3, 4, 5, and 6 μm. Black, red, green, and blue lines stand for the emittance measured at 373, 473, 573, and 673 K, respectively. Measurements are normalized to the emissivity of polished n-type Si.

3D macroporous Silicon

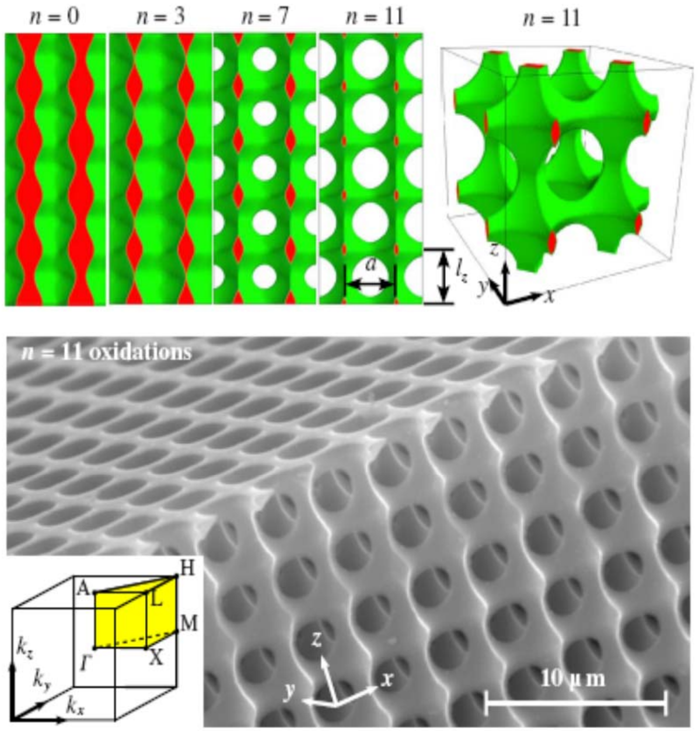


FIG. 1. (Color online) (Top) Computer-generated representation of the pore-widening process for several oxidation/oxide removal steps, n. The in-plane periodicity a equals the periodicity l_z along the pore axis direction. (Bottom) SEM of a macroporous sample after 11 oxidation/oxide removal steps. The inset represents the irreducible Brillouin zone.

M.Garin et al APL 2008

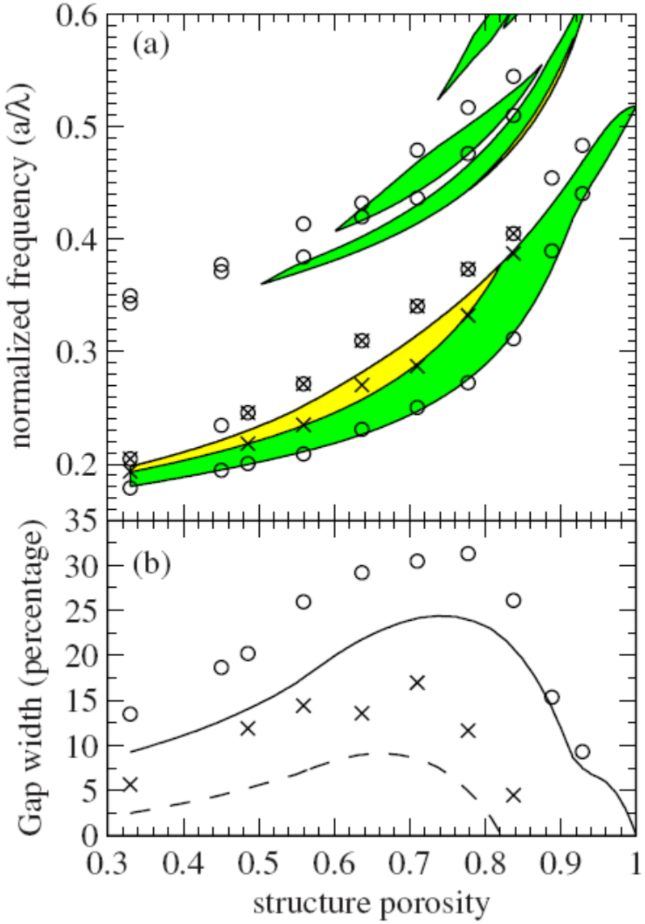


FIG. 2. (Color online) (a) Map of the main Γ-A gaps (green/gray) and OTR bands (yellow/light gray). (b) Gap width to midgap ratio of the first Γ-A gap (solid) and the OTR band (dashed). The symbols represent the edges of the measured Γ-A gaps (circles) and OTR bands (crosses).

3D from 4→2 μm pitch

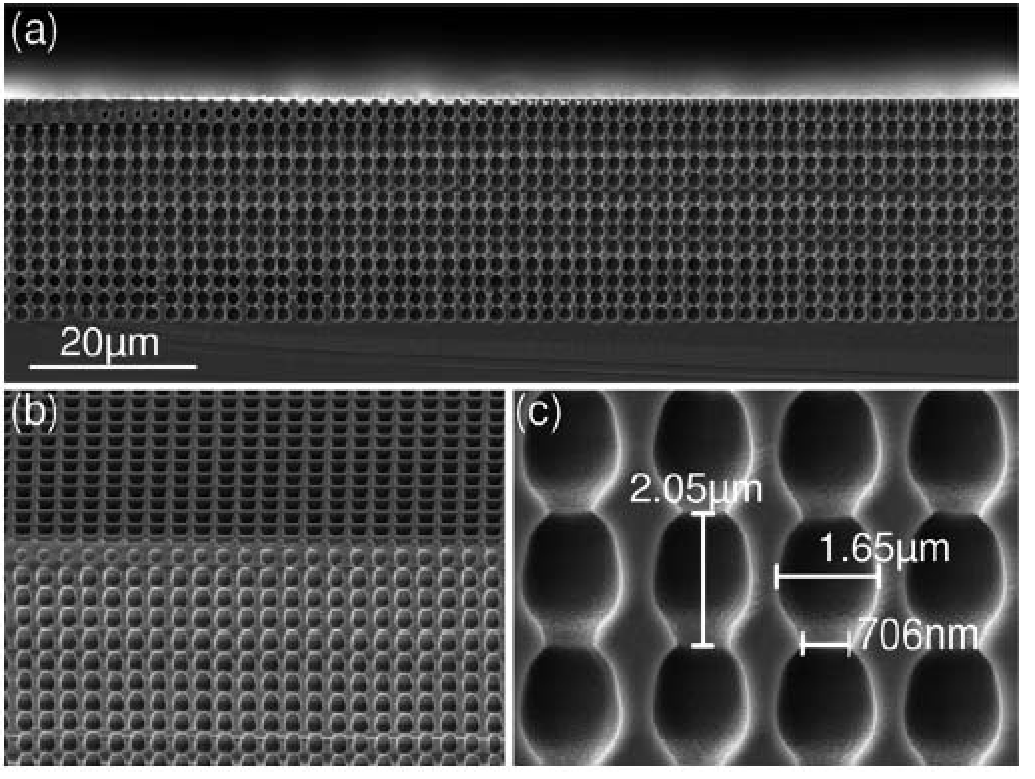
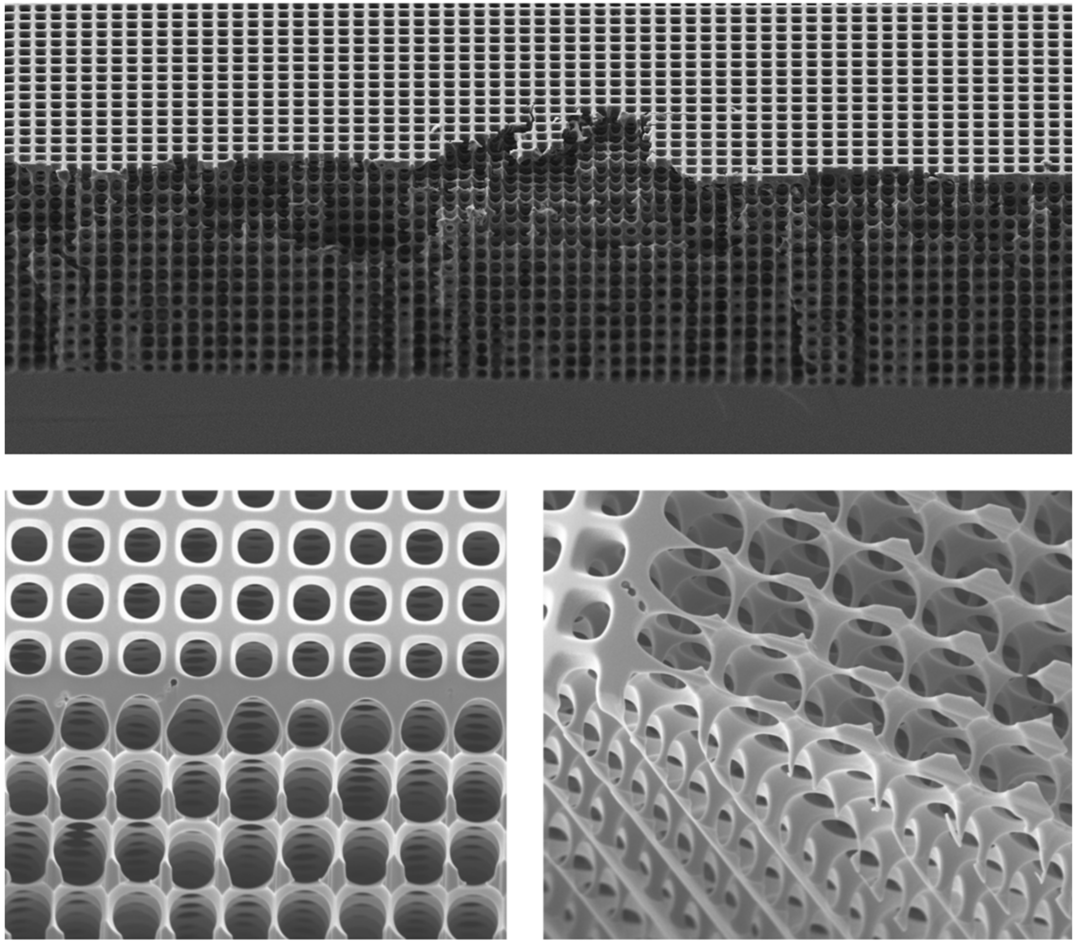


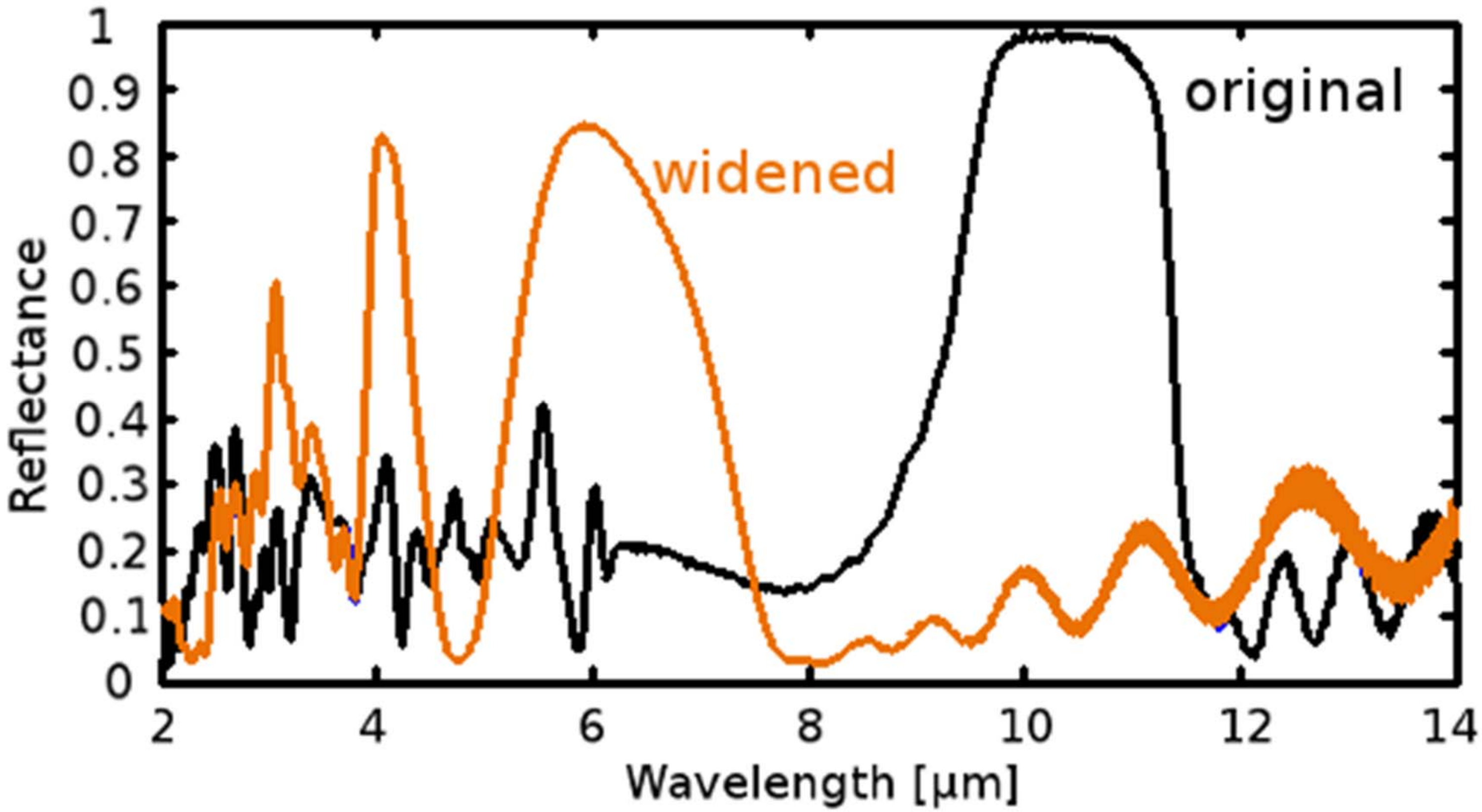
FIG. 1. (a) Cross-section image showing the uniformity of the fabricated structure. (b) Tilted-view showing the square arrangement of the pores. (c) Closer-view image showing the pore modulation in depth.

Appl. Phys. Lett. **100**, 091901 (2012)

3D, 2 μm pitch + widening through oxidation +etching

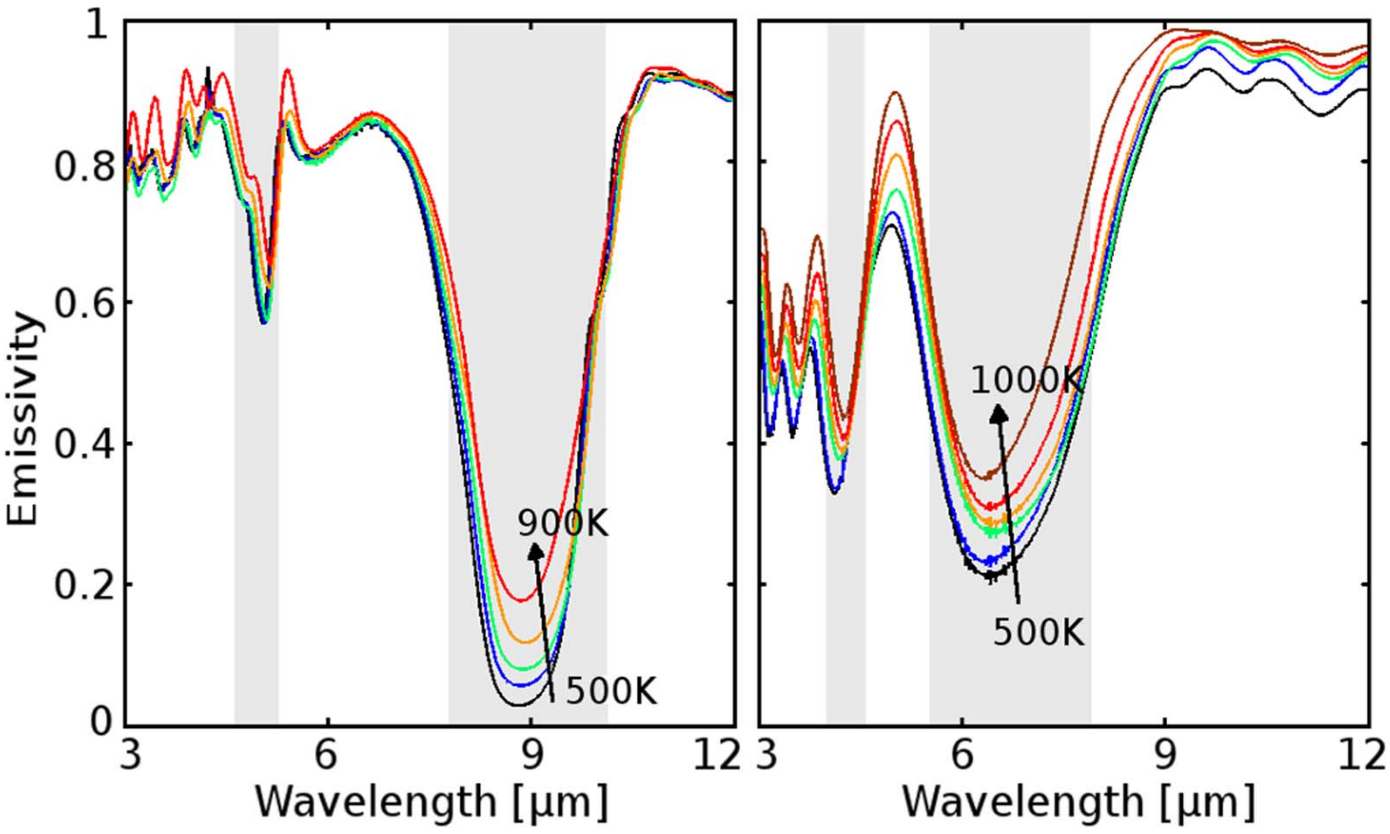


3D from 4→2 μm pitch + widening through oxidation +etching



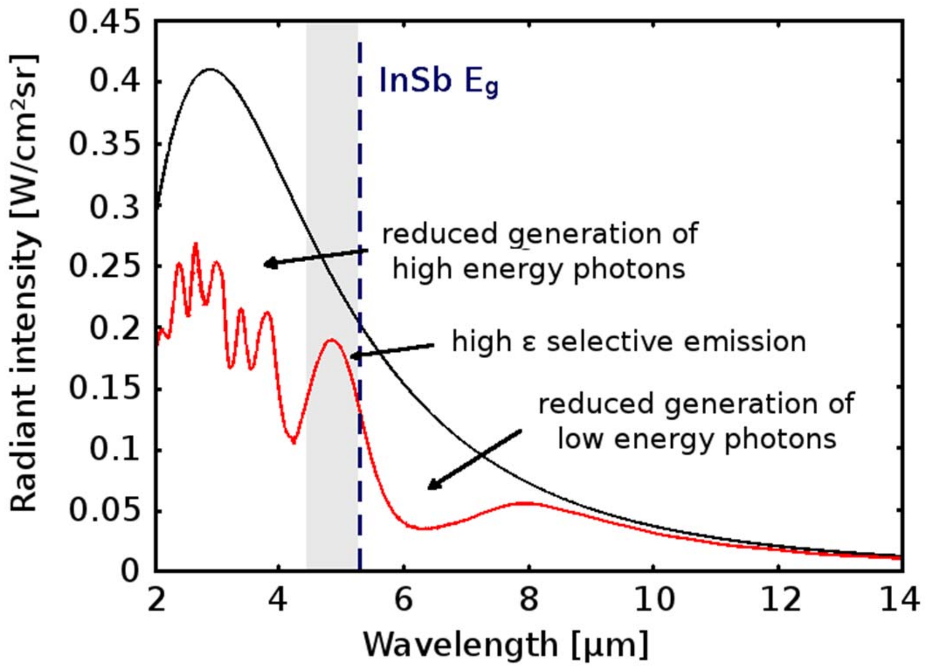
Room temperature measurements

3D, 2 μm pitch + widening through oxidation +etching



a) Two widening cycles. b) Six widening cycles.

3D from 4→2 μm pitch + widening through oxidation +etching

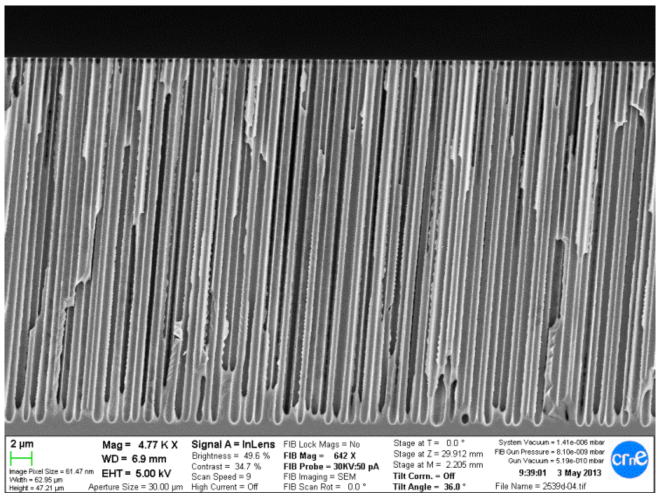


1000K

- Efficiency not so different from BB

$$\eta = \frac{\int_{Eg}^{\infty} W(E)dE}{\int_{0}^{\infty} W(E)dE}$$

- Reduce pitch from 2→1 μm



ALD Pt on 3D PC samples.

-Generic problems when introducing metals:

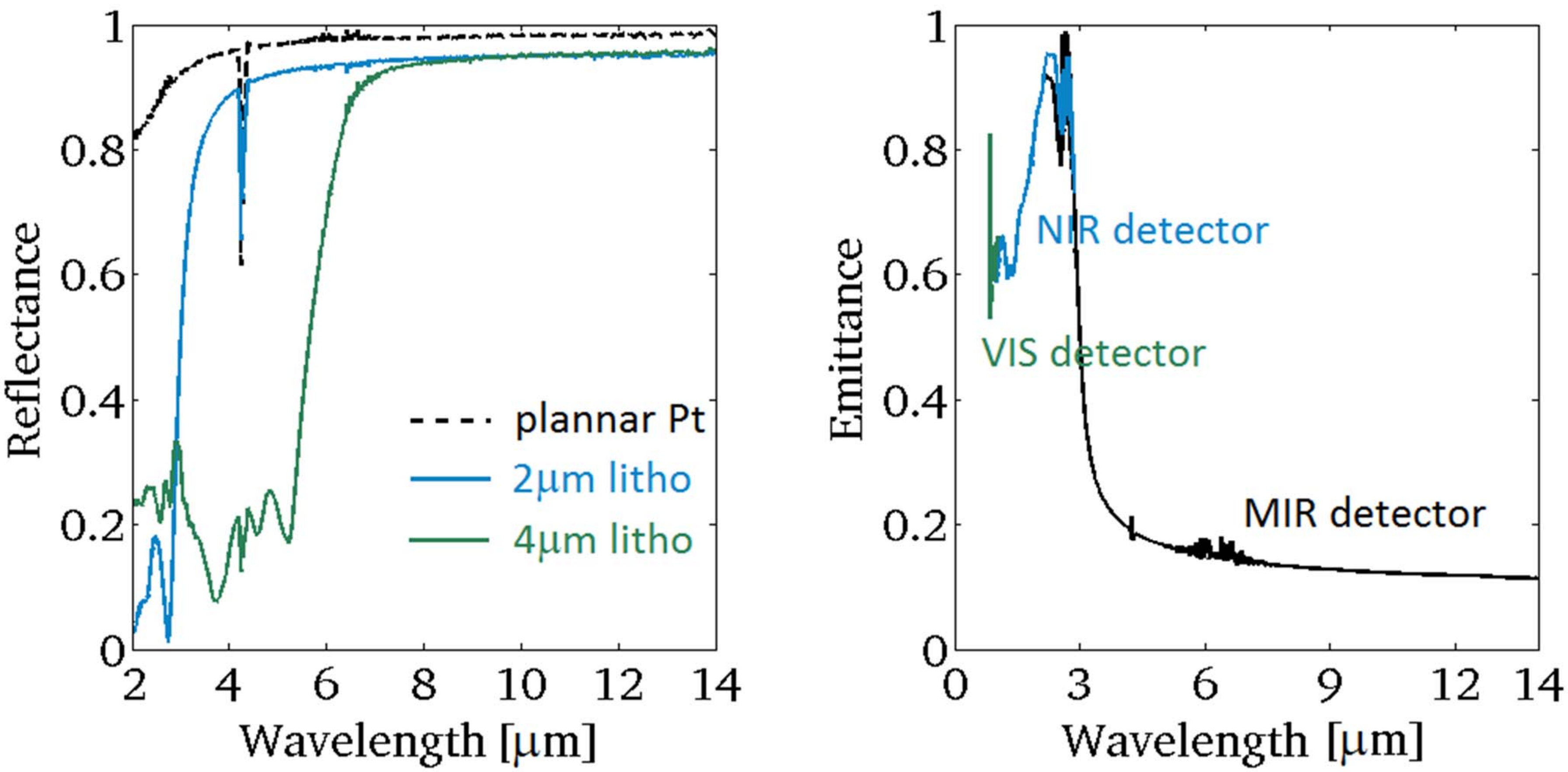
Surface diffusion→ Changing shape.

Eutectics.

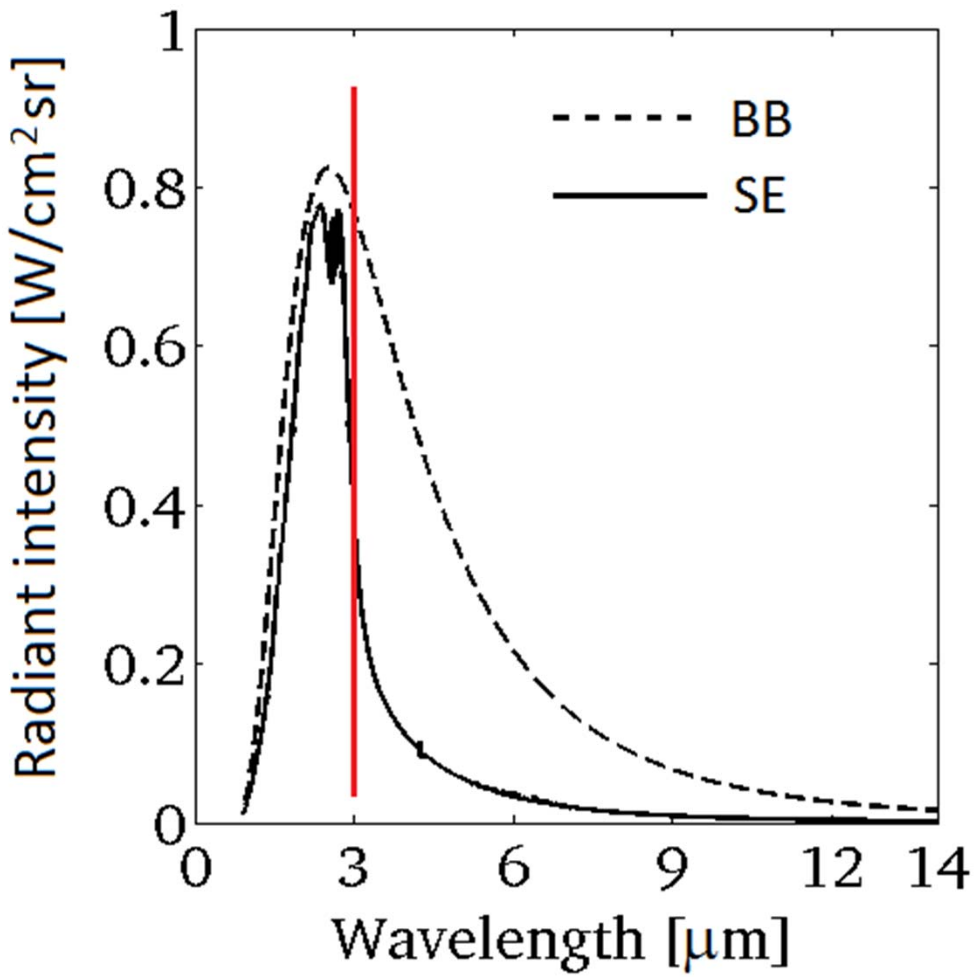
- ALD (Atomic Layer Deposition) on 3D samples.
  conformal deposition.

- Cover Si with SiO2 or may be with Al203 to avoid eutectics.

ALD Pt on 3D PC samples.



ALD Pt on 3D PC samples.



1150 K

$$\eta = \frac{\int_{Eg}^{\infty} W(E)dE}{\int_{0}^{\infty} W(E)dE}$$

η_E^{SE} = 71.6%

η_E^{BB} = 38.2%

Stability: 1050 K 12 hours
Bowing. 1150 K 12 hours

Thank you !